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STUDIES OF THE SOLAR AND TERRESTRIAL RADIATION FLUXES OVER ARCTIC PACK ICE

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STUDIES OF THE SOLAR AND TERRESTRIAL RADIATION FLUXES OVER ARCTIC PACK ICE

Bjorn Holmgren
and
Gunter Weller

FINAL REPORT

Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

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13. ABSTRACT

This report describes some measurements carried out during 1972 AIDJEX that have not been accounted for in earlier reports under this contract. Determinations of the turbidity coefficient gave a mean value of 0.078, indicating that the dust scattering is considerable in the Arctic atmosphere. Incoming and outgoing short-wave and long-wave radiation fluxes were monitored by 4 Eppley precision pyranometers. The variations of these fluxes and of the radiation balance are discussed, especially in relation to the cloud conditions.

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FOREWORD

This is the Final Report (Technical Report No. 3) covering the period June 1 1971 through 31 December 1972 on Contract N00014-71-A-0364-0001.

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INTRODUCTION

Our studies have concentrated on determining the physical characteristics of pack ice, clouds and aerosols as they affect the Arctic radiation regime. At Barrow, flights through stratus clouds with aircraft mounted continous cloud particle samplers have determined number and mass densities, particle size distributions and ice crystal contents of these clouds over a wide temperature range. Simultaneously, light intensity and reflectivity measurements have been carried out to determine the optical properties of these clouds.

Aircraft-mounted photometers have provided measurements that have allowed deduction of aerosol profiles up to 13,000 feet; on two occasions these were extended up to 35,000 feet aboard flights by the NASA CV-990 aircraft to the Arctic Ice Dynamics Joint Experiment (AIDJEX) camp in the Beaufort Sea. Although the air is fairly "clear" over the Arctic Ocean, ice crystal and other aerosols are present, and are important in scattering incoming radiation. In addition to measurements of ice nuclei concentrations at Barrow, actinometric observations were made on numerous occasions at the AIDJEX camp, occasionally through ice crystal clouds advected from open leads.

Routine monitoring of components of the radiation balance have been carried out at Barrow, Ice Island T-3 and the AIDJEX camp. Coupled with this were studies of surface inhomogeneities, such as hummocks, snow dunes, leads and pressure ridges, and the effects of these features on the surface albedo and temperature. Of particular interest were the measurements over refreezing leads, both artificially made and natural ones, showing extraordinary modification of the radiation balance during the freezing process. Light extinction measurements in snow, ice and sea water, using photocells, allowed the construction of a typical extinction nomogram for these studies.

One important part of our work has been theoretical modeling in order to synthesize our observations of radiation fluxes and of surface and atmospheric radiation characteristics. For infrared fluxes we have developed a fairly elaborate model which allows computation of radiation transfers in an atmosphere with several cloud layers, for short wave fluxes we have so far developed a rough model which shows the effect of a thin cloud layer on the radiation balance of the earth-atmospheric system at various latitudes and seasons.

Our main research efforts were accounted for in the Annual Report (Technical Report No. 2), where the overall research objectives were also described. In the present report we comment on a few measurements which had not been subject to analysis when the Annual Report was written.

Our original intention was that this project should develop into a broad study of the radiation regimes of the Arctic which could be related to such considerations as the heat budget of the Arctic Ocean and the stability of the Arctic climate. We feel that our basic approach has been sound and that we have made progress in attaining our objectives. We regret that our research has ended prematurely.

ON THE TURBIDITY OF THE ARCTIC ATMOSPHERE

During the AIDJEX pilot study in April 1972, we made approximately 100 measurements of the direct solar intensity by means of a Linke-Feussner actinometer furnished with Scott color filters OG_1 and RG_2. These measurements, representing 10 days with clear sky conditions, although in some cases with visible ice crystal aerosols present, have been analyzed to determine the turbidity coefficient β (Figure 1) and the water vapor absorption F (Figure 2) by applying the so called Angstrom-Hoelper method (Hoelper, 1935). The average β values for the 10 days was 0.078, which is higher than might be expected. On the other hand, the corresponding F values seem to be somewhat low (compare e.g. Liljequist,1956). There are indications, judging from the low F value and also from the relationships between F and airmass m_h, that our β values for some reason or other may be too high by 0.005 - 0.010 units.The determination of the atmospheric turbidity parameters requires accurately calibrated instruments including the filter factors. In our study we have used the Linke-Feussner actinometer with the temperature-corrected calibration constant recommended by the factory. Preferably, a standard pyrheliometer should be applied to support the factory calibrations in order to ensure maximum reliability of the data.

However, also with these qualifications in mind, it is obvious that the scattering and absorption by particles in the Arctic atmosphere is considerable and cannot be neglected in considerations of the energy budget of the surface atmosphere system. For a solar elevation of 30° above horizon our β values correspond to a decrease of the direct solar radiation by about 20% as compared to the conditions in an atmosphere without dust scattering. On the other hand, the influence of the dust scattering on the total incoming solar radiation at the surface is relatively small over a large snowfield, since increased diffuse sky radiation to a large extent compensates for the loss of direct solar radiation.

Very little seems to be known about the characteristics of aerosols in the Arctic atmosphere, their chemical composition, residence times etc. Fletcher (1966) points out the prevalence of ice crystal haze, especially during the dark months, and discusses its effect on the long-wave radiation budget of the surface atmosphere system. Although ice crystal aerosols certainly contributed to the β values observed at the AIDJEX camp, we can at the present time only speculate as to how important this contribution is compared to aerosols of other origin.

Earlier measurements of β in the Arctic indicate a seasonal variation with relatively high values in early spring and markedly lower values in summer (Figure 3). Further information, especially on the vertical distribution of aerosols is given by Shaw (Technical Report No. 2 under this contract). Measurements with aircraft mounted photometers showed an approximately exponential decrease of the aerosol extinction coefficient with increasing elevation, with a dust sphere scale height amounting to 1-2 km. From β determinations at sea-level and at an altitude of 1300 m Holmgren (1971) found an average scale height of 3.2 km in May and 1.6 km in July, indicating that the decrease of β during this period (Figure 3) was mainly due to a decrease of the dust extinction in the atmosphere above the 1.3 km altitude.

MONITORING OF THE RADIATION BALANCE DURING AIDJEX

Our AIDJEX study in April 1972 sought to determine numerically the highly variable radiation related characteristics of the Arctic environmental features, schematically depicted by the matrix of Appendix I. The result of the measurements of these characteristics were described in the Annual Technical Report No.2. We will here briefly describe some temporal variations of radiation fluxes as measured over snow covered multi-year pack ice and the relationships between these variations and the cloud conditions. The net radiation was monitored by measurements of its four basic components, incoming and outgoing long wave and short wave fluxes using Eppley precision pyranometers. Numerous calibrations were carried out, against a Linke-Feussner actinometer for short wave radiation, and against a Barnes PRT-5 precision thermal radiometer for long wave radiation. Continuous records were obtained from April 2 throughout April 26 except for two days when we had troubles with recording the data. Although the data were thus collected during a relatively short period there are several interesting features that can be deduced from the curves of Figure 4 (numerical values given in Table 1).

1. The AIDJEX data were collected at a time of the year when the all-wave radiation balance is going from negative to positive daily values on the average. During clear sky conditions the radiation balance is negative, while the balance is positive with an overcast sky. It may be noted that the radiation balance over an open lead in the beginning of April was found to be -100 cal cm^{-2} day^{-1} (Technical Report No. 2).

2. During the cloudy period from April 12 throughout April 17 the albedo of the snow is notably high. This feature is probably primarily related to multiple reflections between the snow surface and the clouds.

The incoming solar radiation becomes enriched in visible radiation which has a higher reflectivity than the near infrared radiation. New snow deposited during this period might also have had an effect on the increase of the albedo.

3. The incoming solar radiation does not decrease very much when a cloud cover forms over an extensive snow-field. During the six days with overcast sky or varying cloud conditions in the middle of April, the average decrease of the incoming radiation because of the clouds is only about 15%. On the other hand, the <u>absorbed</u> short-wave radiation decreases substantially because of the increase of the albedo.

4. During the same period there is a marked increase in the incoming and on the average a small increase in the outgoing long wave radiation, resulting in a marked decrease of the long wave radiation losses.

5. The net long wave and the net short wave radiation balances are negatively correlated. The variations of the net long wave radiation are the greater and therefore dominate the variations of the all wave radiation balance.

In summary, Figure 4 provides interesting information on the interactions between the radiation fluxes during varying cloud conditions. One could only wish that similar data were available on an annual basis. In the literature we have not as yet seen any results of direct measurements of all four basic components of the radiation balance. It seems evident that long wave pyranometers are valuable tools in climatological studies of the radiation balance. One word of caution may be appropriate. We have so far not made extensive tests of the accuracy of the long wave radiation measurements. Our experience is that the calibration factors may be subject to changes after some time of use. Periodic checks of the calibration factors must be carried out. This is also in accordance with the manufacturer's recommendations.

Table 1.

DAILY RADIATION DATA - AIDJEX, APRIL 1972
(cal cm^{-2} day^{-1})

Date	Short W. in	Short W. out	Short Albedo	Long W. in	Long W. out	Net long W.	Net Short W.	All-wave Net
April 2	230.4	171.8	0.80	334.7	411.7	-77.0	58.6	-18.4
3	259.1	202.8	.78	351.3	425.7	-74.4	56.3	-18.1
4	264.2	204.5	.77	345.5	426.8	-81.3	59.7	-21.6
5	282.7	229.2	.81	341.8	413.9	-72.1	53.5	-18.6
6	286.4	221.5	.77	347.8	418.2	-70.4	64.9	-5.5
7	265.7	219.9	.79	376.9	429.1	-47.6	45.7	-1.8
8	287.5	233.7	.81	365.4	432.3	-66.9	53.8	-13.2
9	312.5	249.5	.80	328.4	418.3	-89.9	63.0	-26.9
10	320.9	249.1	.78	313.5	418.1	-104.6	71.9	-32.8
11	332.5	252.9	.76	323.7	431.6	-107.9	79.6	-28.3
12	285.9	240.1	.84	398.6	448.7	-50.1	45.8	-4.3
13	317.3	253.1	.80	406.1	471.0	-64.9	64.2	-0.7
14	283.0	239.8	.85	461.3	485.6	-24.4	43.3	18.9
15	316.0	283.3	.90	441.6	461.8	-20.2	32.7	12.5
16	300.7	262.4	.87	412.8	446.0	-33.2	38.3	5.1
17	364.3	302.9	.83	367.1	454.4	-87.3	61.4	-25.9
18	402.1	307.1	.76	328.7	444.3	-115.5	95.0	-20.6
19	411.4	322.6	.78	341.0	446.3	-105.3	88.8	-16.5
20	370.3	299.5	.81	366.1	449.8	-83.7	70.9	-12.8
22	433.4	336.2	.78	350.3	447.5	-97.2	97.2	0.0
24	452.0	346.5	.77	348.9	458.6	-109.7	105.5	-4.2
25	477.2	368.6	.77	346.3	470.0	-123.7	108.7	-15.0
26	487.7	376.1	.77	353.6	474.0	-111.3	111.7	0.4

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FIGURE CAPTIONS

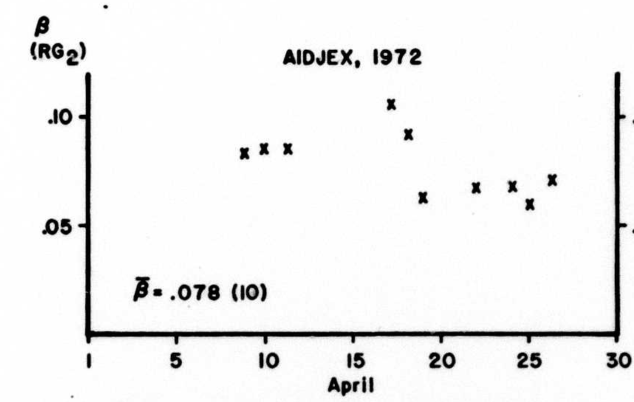
Figure 1 Daily values of the turbidity coefficient β determined from actinometric measurements during 1972 AIDJEX.

Figure 2 Water vapour absorption F of solar radiation determined by applying the Angstrom-Hoelper method to actinometric measurements during 1972 AIDJEX.

Figure 3 Variations of the turbidity coeffieient β as measured at selected stations in the Arctic.

Figure 4 The variations of radiation components using Eppley precision short wave and long wave pyranometers during 1972 AIDJEX.

c - clear sky
v = variable cloud conditions
o = overcast sky



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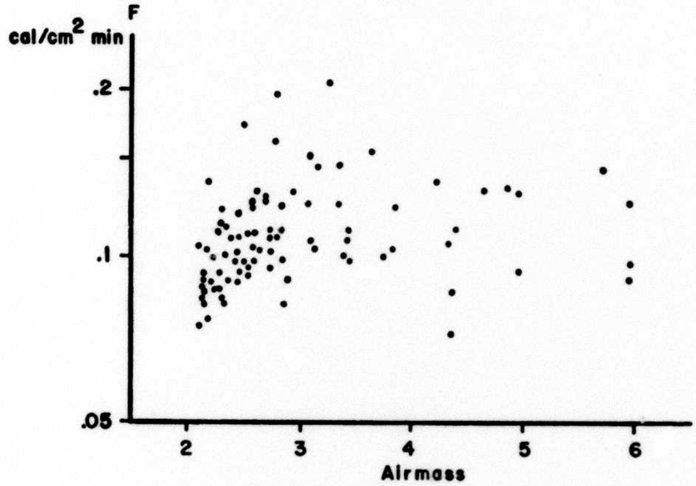

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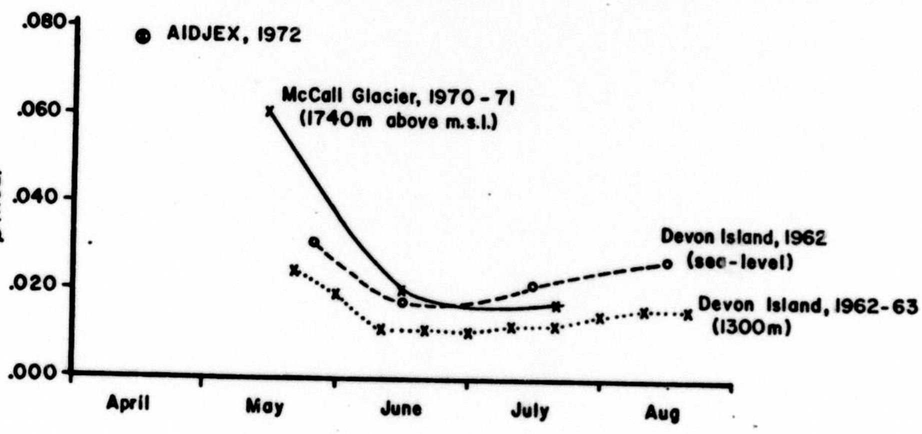

Figure 3 Variations of the turbidity coefficient β as measured at selected stations in the Arctic.

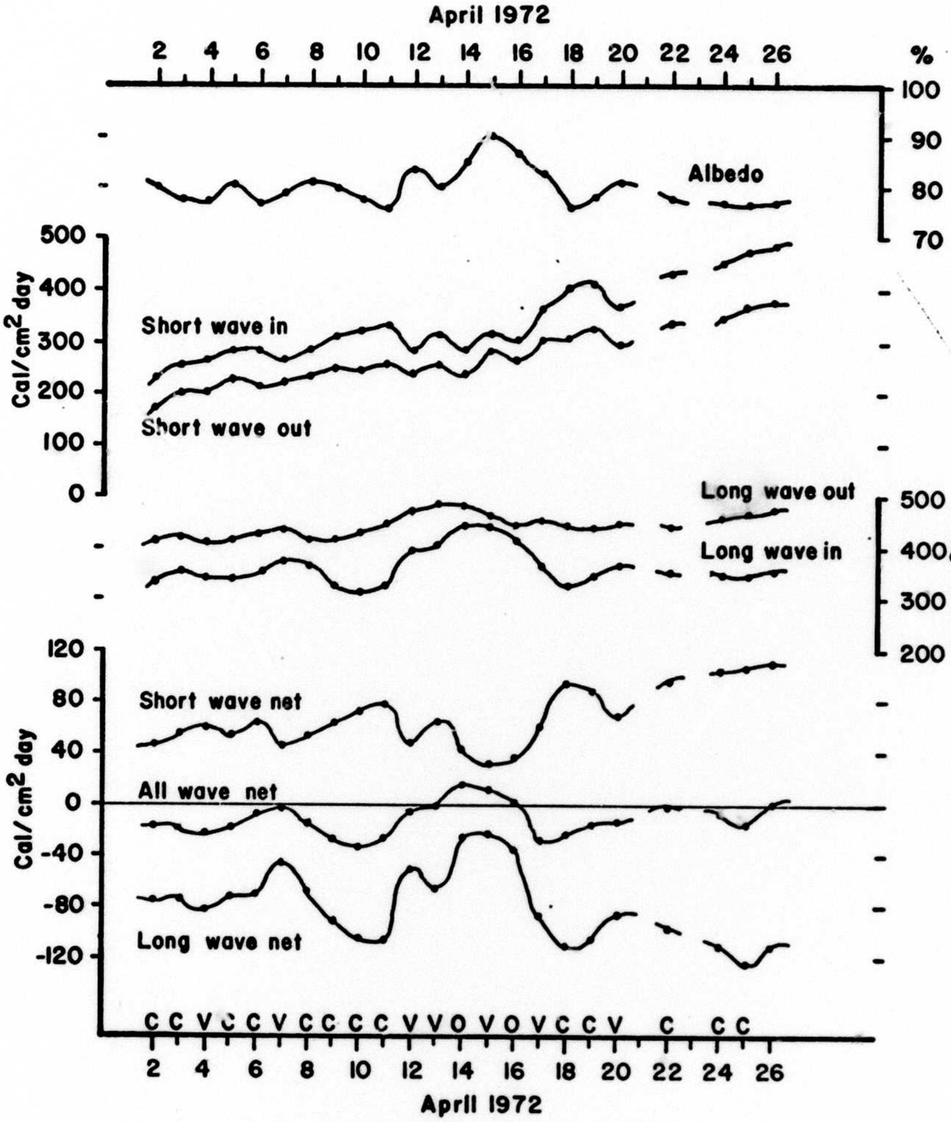

Figure 4 The variations of radiation components using Eppley precision short wave and long wave pyranometers during 1972 AIDJEX.

c - clear sky
v = variable cloud conditions
o = overcast sky

APPENDIX I

RADIATION FLUX INVESTIGATION
by
G. Weller

Published in AIDJEX Bulletin No. 14
July 1972

RADIATION FLUX INVESTIGATION

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The energy balance at the ice/air interface in the Arctic is dominated by the radiation fluxes. The 1972 study sought to determine numerically the highly variable radiation-related characteristics of the arctic environmental features shown in the matrix below. An x denotes those elements investigated during AIDJEX 1972.

COVERAGE OF RADIATION FLUX STUDY, AIDJEX 1972

Features	*Surface Temps., Infrared Flux Emitted*	*Surface Reflectivity, Albedo*	*Extinction Coefficient*	*Radiation Balance, 4-component*
Sea water	x	x	x	x
Sea ice (multiyear)	x	x	x	x
Refreezing leads				
Natural	x	x	x	x
Artificial	x	x		x
Hummocks, ridges	x	x		
Snow cover	x	x	x	
Atmosphere (clear)	x		x	
Aerosols (ice crystals)	x		x	

Of particular interest were the radiation balance measurements over refreezing leads, both natural and artificially made. Figure 1 shows that the measured open-lead values compare well with those computed by Badgley and by Doronin [Fletcher, J. O. 1965. *Heat Budget of the Arctic Basin and Its Relation to Climate*, The Rand Corp., R-44-PR]. The net radiation loss of open leads is an order of magnitude higher than that of multiyear ice at this time of year, and remains much higher for several weeks after freezing.

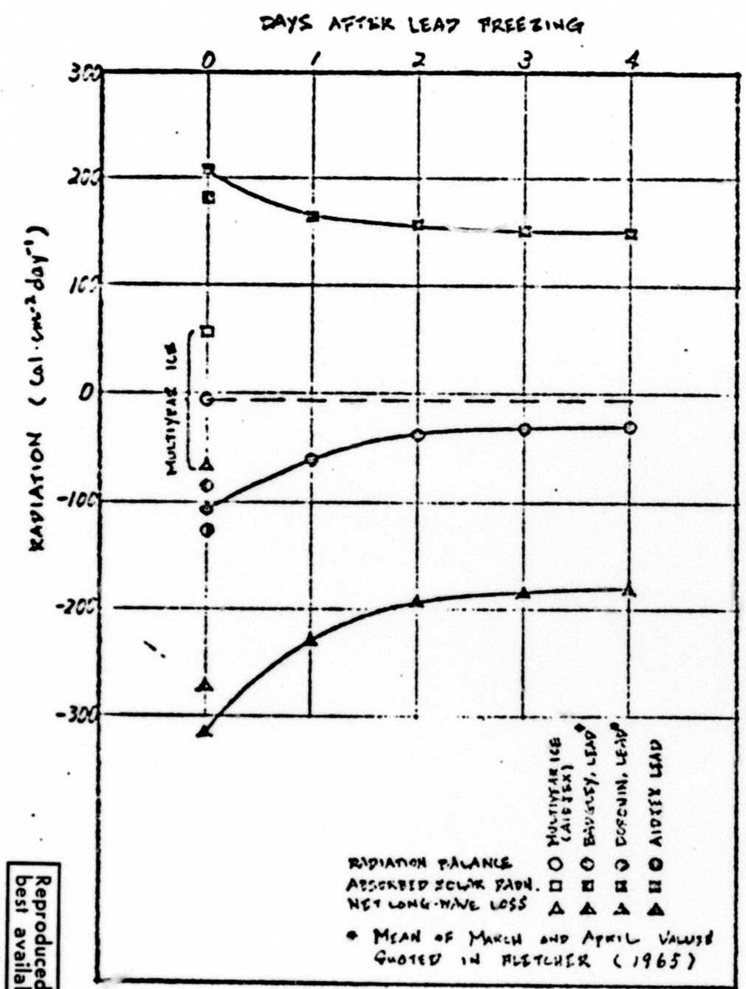

Fig. 1a. Radiation balance of a refreezing lead. AIDJEX 1972, 3-7 April.

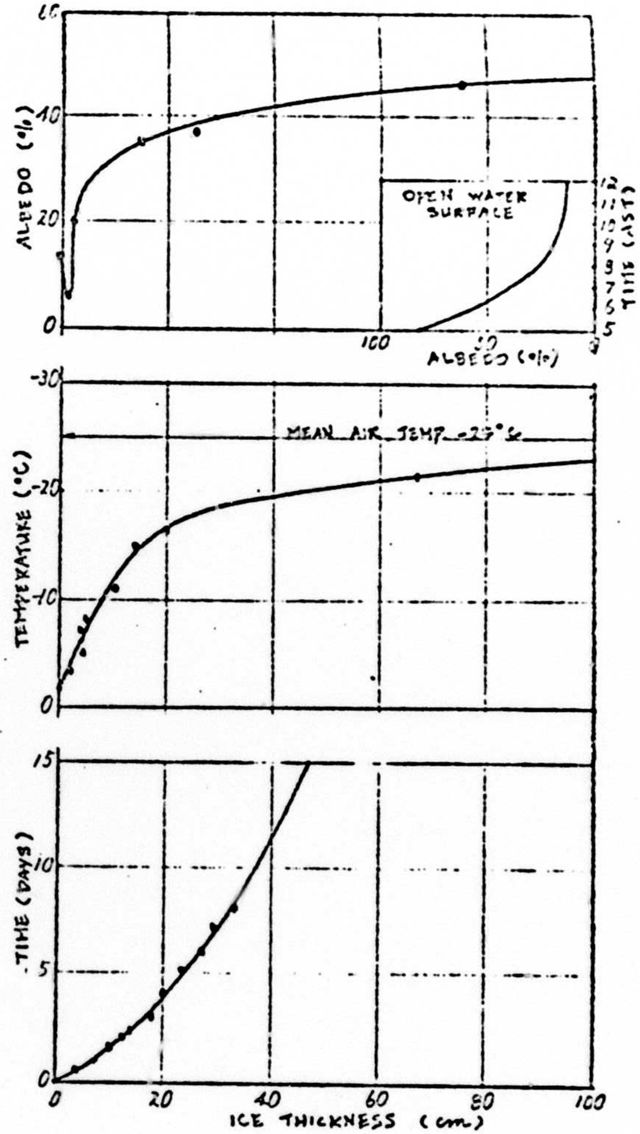

Fig. 1b. Rate of freezing, surface temperature, and albedos of a refreezing lead.

Albedo measurements were made from the ground with fixed and portable equipment and from the air during photographic runs with Twin Otter aircraft flying at altitudes of 1500, 5000, and 12,000 feet. The aerial albedos show a strongly skewed frequency distribution because of the presence of leads; they also show a mean albedo for multiyear ice of .78.

Light extinction measurements, by photocells, in snow, ice, and sea water allowed the construction of a typical extinction nomogram for these substances. For example, 10 cm of snow overlying 2 m of sea ice reduces the light intensity at the ice/water interface to half a per cent of that at the surface. Similarly, light extinction caused by turbidity in the atmosphere was measured with various filters on numerous occasions, both through "clear" air and through dense ice crystal aerosols near the ground. Brilliant and complex solar halos, usually present during these latter conditions, were observed and recorded on several occasions. Similar measurements were made aboard the NASA CV-990 aircraft on two flights, obtaining profiles from 32,000 feet down to 500 feet above the ice surface.

Surface temperature maps on a microscale were constructed from measurements under different conditions of sky cover and wind for a variety of surface features. Observed differences on sunny and shady sides of hummocks on clear and relatively calm days were as much as 8°C. These data were always collected during NASA CV-990 overflights, as well as on other occasions, to allow comparison with the aircraft remote-sensing equipment.

Routine monitoring both of the four components of the radiation balance over multiyear ice by using Eppley precision pyranometers and of the short-wave diffuse sky radiation continued uninterruptedly throughout the experiment. Calibration against a substandard was carried out *in situ* on all instruments to determine cosine errors. An air blower system designed for the experiment successfully kept the sensors free of frost deposit throughout the period of observation.

Field Personnel: Gunter Weller, 31 March-18 April; Stan Parker, 31 March-25 April; Tom Goldthwait, 11-29 April.

APPENDIX II

THE SIZE DISTRIBUTION AND CONCENTRATION OF CLOUD PARTICLES IN ARCTIC CLOUDS

by

K.O.L.F. Jayaweera

Abstract of paper presented at the International Cloud Physics Conference in London, August 21-26, 1972, sponsored by ICCP, IAMAP, and IUGG.

The Size Distribution and Concentration of Cloud Particles in Arctic Clouds

by

K.O.L.F. Jayaweera [1]

Clouds over land in the polar regions near the sea are typically stratus and occur in layers about 3000 feet thick and separated by about 1000 feet. Any other cloud formation is only exceptional and is rarely seen. The composition of these clouds were investigated using an MRI cloud particle sampler fitted to a Cessna 180 in the vicinity of Barrow, Alaska, during the month of September 1971. During this month the clouds extended from 800 feet to 12,000 feet and 35 passes were made at different temperature levels ranging from +2C to -11C. At each pass the volume of air sampled were about 500 liters. The purpose of these investigations were to establish the conditions under which ice particle multiplication does or does not take place and to determine the importance of ice nuclei on the ice crystal development in clouds.

The ice crystal observed in these clouds were all columnar and unrimed. The concentration of ice crystals at -11C and -7C were about 40 per m^3 and 10 per m^3 respectively and at -4C it was less than 2 per m^3. These values agree well with the average ice nuclei concentrations at the corresponding temperatures, measured using Millipore samples collected at Barrow during this period and developed using the technique of Stevenson (1970). The ice crystals at -7C were sheaths and were larger than the solid columns observed at -11C. The sheaths had diameters near 30 μm and lengths about 100 to 200 μm, while solid columns were about 20 μm diameter and 50 μm length. The water droplet concentrations and spectrums were analysed for each pass. The size spectrums did not vary significantly at different levels, hence in Fig. 1 the overall size spectrum is shown. These values were corrected for the collection efficiency of the sampler which has a zero value for droplets

1. Geophysical Institute, University of Alaska, College, Alaska

less than 3 μm and almost 100% for drops greater than 35 μm. The concentrations on most occasions were about 90 per cm^3 while the highest were 160 per cm^3, giving a liquid water content of 0.2 to 0.3 gm per m^3. Therefore, our analysis shows that the characteristics of the arctic stratus does not vary from day to day or at different levels, has a narrow spectrum without any big drops, and lie between the stratus clouds observed in Germany and Hawaii (Mason, 1971).

In conclusion, the results of the study at Barrow suggest that in clouds with narrow droplet spectrum and without any big drops the concentration of ice crystals can be determined from the laboratory measurements of ice nuclei and indicate that ice particle multiplication is found only in clouds that has big drops or rimed ice particles or both. These observations agree with the contention of Mossop (1971) on the factors necessary for ice multiplication in clouds.

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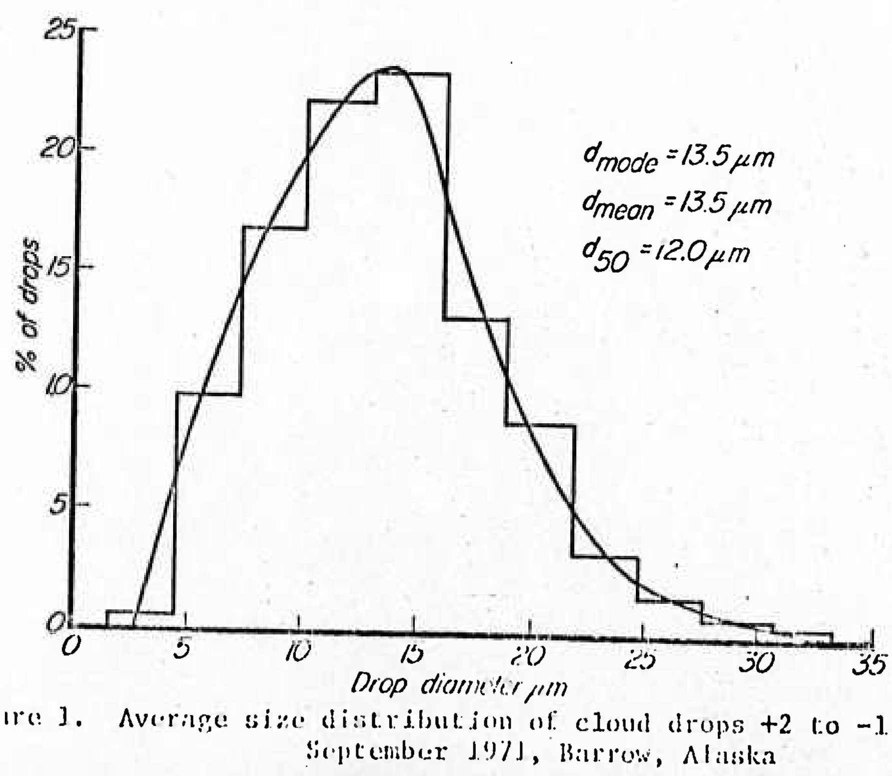

Figure 1. Average size distribution of cloud drops +2 to -11C September 1971, Barrow, Alaska

APPENDIX III

AIRBORNE OPTICAL MEASUREMENTS OF ATMOSPERIC AEROSOLS NEAR BARROW, ALASKA

by

G. Shaw and G. Weller

Abstract of paper given at the AGU Vancouver meeting, October 16, 1972

AIRBORNE OPTICAL MEASUREMENTS OF ATMOSPHERIC AEROSOLS NEAR BARROW, ALASKA

Glenn E. Shaw, Gunter Weller

The change of direct solar radiation with altitude is related to the vertical profile of the aerosol optical extinction coefficient. An airborne photometer experiment was performed to measure the solar radiation at multiple narrow wavelength intervals in the visible region. Measurements that were taken near Barrow, Alaska (latitude 71°30'N, longitude 156°30'W) are summarized, and results of analyzed records showing typical profiles of aerosol extinction coefficients along with their relation to meteorological parameters are described.

APPENDIX IV

SOME RESULTS OF RADIATION MEASUREMENTS DURING THE 1972 AIDJEX PILOT STUDY

by

B. Holmgren and G. Weller

Abstract of paper presented at the AGU Meeting in San Francisco, December 4-7, 1972.

SOME RESULTS OF RADIATION MEASUREMENTS DURING THE 1972 AIDJEX PILOT STUDY

by

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The extinction of the direct solar radiation by dust scattering, as determined by a Linke-Feussner actinometer with color filters, was unexpectedly high with a mean value of the Angstrom turbidity coefficient $\beta \approx 0.07$ for 10 days with clear skies. A comparison with earlier investigations of β in the Arctic indicates a seasonal variation with relatively high values in early spring and markedly lower values in summer.

Measurements of the albedo over snow-covered multi-year ice gave a mean value of 78% for 12 days with clear skies, and 87% for 4 days with overcast skies. The increase of the albedo in connection with a clouding over may probably be ascribed to multiple reflections between the cloud-base and the snow surface. By applying a simplified scheme for the radiation transfer through clouds and by assuming representative values of the surface reflectance in the visible and infrared regions of the solar spectrum, it is argued that multiple reflections between the surface and the clouds should also have a marked effect on the spectral composition of the incoming solar radiation and on the albedo of the melting pack ice in summer. Measurements of the surface reflectance within narrow spectral intervals and for various surface types appear to be needed before realistic modeling of solar radiation fluxes over the pack ice can be made.

The radiation balance over snow-covered multi-year ice was monitored by four radiometers (2 short-, 2 long-wave) supplied with a warm-air blower system to prevent frost deposits. During a fine-weather period with air temperatures at around -25°C in early April, the radiation balance over open and refreezing leads was monitored by additional measurements of the albedo and the emitted long-wave radiation. The radiation balance over open leads was found to be -100 cal cm^{-2} day^{-1}, while the concurrent radiation balance over multi-year ice was close to zero. The freeze-up of a lead brought about at first rapid, later more gradual changes of the surface temperature (decreasing) and of the albedo (increasing). As the freezing of the lead continued, its radiation balance approached that of multi-year ice asymptotically.